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RESEARCH MEMORANDUM

FLIGHT TESTS OF AN AUTOMATIC INTERCEPTOR SYSTEM WITH A TRACKING RADAR MODIFIED TO MINIMIZE THE INTERACTION BETWEEN ANTENNA AND INTERCEPTOR MOTIONS

By William C. Triplett and Francis W. K. Hom

Ames Aeronautical Laboratory
Moffett Field, Calif.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

May 22, 1957

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RESEARCH MEMORANDUM

FLIGHT TESTS OF AN AUTOMATIC INTERCEPTOR SYSTEM WITH A TRACKING RADAR MODIFIED TO MINIMIZE THE INTERACTION BETWEEN ANTENNA AND INTERCEPTOR MOTIONS

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SUMMARY

Analog-computer studies reported in NACA RM A56K19 show that the over-all performance and particularly the flight path stability of an automatic interceptor system is seriously influenced by imperfect space stabilization of the radar antenna. A simple compensating feedback, when studied on the computer, proved to be effective in minimizing the interaction between antenna and interceptor motions. The present report describes a brief flight-test program in which a similar modification was installed in a typical interceptor system, and the results indicate a significant improvement in the over-all response characteristics of the system.

INTRODUCTION

In reference 1, effects of radar space stabilization were discussed. It was shown that an imperfectly stabilized antenna could seriously influence the flight path stability and tracking ability of an automatic interceptor during the final attack. These effects were very pronounced when a typical interceptor system was simulated on the Ames analog computer and were also apparent, to a lesser degree, in flight tests of the same system. Further study indicated that this problem is inherent in any system that utilizes a space-stabilized antenna. A modification of the radar circuitry designed to isolate the antenna from interceptor motions appeared to be very effective when examined on the analog computer and completely eliminated the stability problems that had previously been encountered.

Since the publication of reference 1, a similar radar modification has been checked in flight, and the present report describes the results of these brief flight tests. The effects of improved space stabilization are shown by comparing system responses under similar flight conditions with and without compensation.

NOTATION

A_a	antenna angle in azimuth, deg
A_z	normal acceleration (positive downwards), g
E_a	antenna angle in elevation, deg
M	Mach number
R	target range, ft
$\dot{R}$	range rate, ft/sec
S_j, S_k	steering error signals in azimuth and elevation, respectively, yd/sec
T	time-to-go until impact, sec
W	angular velocity of interceptor in antenna coordinates, radians/sec
p	interceptor rolling velocity, radians/sec
t	time, sec
ϵ_a	tracking error angle of antenna, deg
Ω	angular velocity of line of sight, radians/sec
ω	angular velocity of antenna, radians/sec
ω'	computed antenna rate signal, radians/sec
φ	interceptor bank angle

TEST EQUIPMENT

The interceptor used in the present tests is shown in figure 1 and is the same as described in reference 1; that is, an F-86D airplane with an E-4 fire-control system and a Hughes developed automatic attack coupler (CSTI).

The radar was modified as shown in figure 2 by adding a feedback of gain K_4 in both the elevation and azimuth channels from the output of the integrating rate gyro to the input of the lead-lag networks in the receiver. A control in the cockpit enabled this feedback to be switched in or out during flight.

The flight instrumentation was the same as described in reference 1.

TEST PROCEDURES

The flight tests consisted entirely of 90° beam collision attacks against an F-84F target airplane equipped with radar reflectors to make its reflection characteristics more typical of a bomber-type airplane. Attacks were initiated with various initial steering errors in azimuth. Successive runs during each flight were made with and without the radar modification operative. All flights were made at an altitude of 30,000 feet with the target and interceptor initially at a Mach number of 0.8.

RESULTS AND DISCUSSION

The results presented herein are based on seven flights in which 18 successful attacks were made with the modified system.

As pointed out in reference 1, a compensating feedback gain of 1.0 should give exact cancellation of the antenna response to interceptor motions, but from a practical standpoint 0.8 was considered to be an optimum value. In the actual system, because of adverse loading effects which tended to saturate the antenna drive, the gain could not be set higher than about 0.7, thus providing only partial compensation. Nevertheless, the flight results verify the conclusions reached in reference 1 and show a general improvement in response which may be characterized as

1. A decrease in the noise level of the steering signals

2. Smaller roll rates and less overshoot in bank angle

3. Less severe transient maneuvers upon entering phases II and III of the attack[1]

4. Better coordination between pitch and roll

These observations are illustrated in figures 3(a) and 3(b) which are time histories of typical long-range beam attacks with small initial steering errors. In both cases lock-on was at a range of 10 to 12 miles with an initial azimuth steering command of 30 to 40 yards per second. This corresponds to a heading error of approximately 6°. During the early part of the attack the azimuth steering signal for the unmodified system exhibits, in addition to radar noise, a well defined oscillation at about 1 cycle per second (fig. 3(a)). This signal is fairly well filtered in the roll channel, however, so that only a slight oscillation is visible on the roll-rate trace. Shortly after the start of phase II, however, the airplane rolls in a direction to give a negative angle E_a, and as E_a reaches a peak of about -32° the azimuth steering signal tends to go unstable, leading to a peak rolling velocity of about 2.6 radians per second. Furthermore, as the bank angle approaches its maximum of 80° there is a sharp pitch-down command. This activity took place with the airplane essentially on course.

Figure 3(b) illustrates a similar attack with the radar modification effective. It can be seen that the general noise level of the steering signals is much lower with no well defined oscillations evident. Furthermore, after entering phase II there is no tendency for the steering signal to become unstable even though E_a reaches a value of -28°. Although a long period oscillation is apparent, p never exceeds 0.8 radians per second, and the variations in normal acceleration are much smaller than shown in figure 3(a).

A number of long-range attacks were made with large initial errors. With the modified system the transient maneuver was generally less severe, that is, lower roll rates and less overshoot in bank angle.

In plotting the steering signals, many of the high-frequency, small amplitude components of noise have been faired out. What appears in the figures is a result of interceptor heading error, low-frequency radar noise, and antenna response to interceptor angular velocities. If the steering signal is too erratic the interceptor is not able to stabilize

[1]Phase II commences when T becomes less than its limit value of 20 seconds. At this time there is a step increase in forward loop gain. Phase III begins at $T = 4.5$ seconds provided $A_a > 19^{\circ}$ and $\dot{R} > 75$ yards per second. In phase III there is no azimuth steering command and the airplane is required to maintain its present heading with wings level; azimuth heading errors are compensated by varying the time and range at which firing occurs.

its flight path along the correct lead-collision course, and hence its chances of being properly aligned at the time of firing are diminished. In this sense, steering signal noise is directly related to hit probability.

In order to obtain a quantitative measure, standard deviations of the steering signals during phases II and III were calculated for a number of runs similar to those shown in figure 3. For these calculations, steering signal data were read at 0.1-second intervals. In each case the lock-on was at sufficiently long range so that initial steering errors were corrected before entering phase II. The following table gives the average values of the standard deviations for the number of runs indicated in yards per second, for S_j and S_k in phase II and S_k in phase III:

	Number of runs	Phase II		Phase III
		S_j	S_k	S_k
Normal radar	31	61.8	44.5	20.4
Modified radar	13	48.7	34.1	14.4

As expected, the standard deviations for the modified system are somewhat smaller during phase II because less maneuvering is required of the interceptor; hence there is generally a smaller pitch error upon entering phase III.

To test the modification under more severe conditions, a number of attacks were made at short range with large initial azimuth errors. Furthermore, the stability of the system was impaired by reducing the space-stabilization loop gain (K_2 in fig. 2) by about 20 percent. Under normal operation a similar reduction could result from improper alignment procedures.

Figure 4 illustrates a pair of attacks in which the initial azimuth error is negative; that is, the interceptor is commanded to roll away from the target, thus causing E_a to become negative. In figure 4(a) the control system was engaged shortly after the start of phase II and the system response is similar but more severe than that shown in figure 3(a). The large erratic variations in S_j and S_k are accompanied by a peak bank angle of 150° and roll rates that reach ±2.5 radians per second. Furthermore, there is rather a severe oscillation in normal acceleration. Figure 4(a) is typical of a number of runs made with similar initial conditions. In some cases the airplane rolled beyond 180° and lost radar contact with the target. The modified system (fig. 4(b)) exhibits a milder variation of S_j. Although the response is still somewhat oscillatory, the maximum bank angle is only 95° and p never exceeds 1.2 radians per second.

Figures 5(a) and 5(b) illustrate a pair of attacks in which a positive steering error commanded the interceptor to roll toward the target, thus creating a large positive value of E_a. The unmodified system clearly exhibits the high-frequency instability in the azimuth steering signal that was previously encountered on the analog computer. (The signals saturate at approximately 300 yards per second.) There is a corresponding oscillation in rolling velocity of about ±0.2 radian per second although the roll angle trace is very smooth. As shown by figure 5(b), the compensating feedback effectively eliminates this type of oscillation.

CONCLUDING REMARKS

Brief flight tests of an automatic interceptor system have been made to check the effectiveness of a radar system modification proposed on the basis of analog-computer studies. This modification, a simple compensating feedback, minimizes the interaction between antenna and interceptor motions which has a serious influence on flight path stability during a lead-collision attack. Flight tests of the modified system clearly indicated that by reducing the disturbance level of the steering signals much of the undesired rolling and pitching motions which may result in low hit probability can be eliminated. Furthermore, the initial response to large steering errors is much less violent, and the ability of the interceptor to lock-on at short range and successfully complete an attack is somewhat improved.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Apr. 9, 1957

REFERENCE

1. Triplett, William C., McLean, John D., and White, John S.: The Influence of Imperfect Radar Space Stabilization on the Final Attack Phase of an Automatic Interceptor System. NACA RM A56K19, 1957.

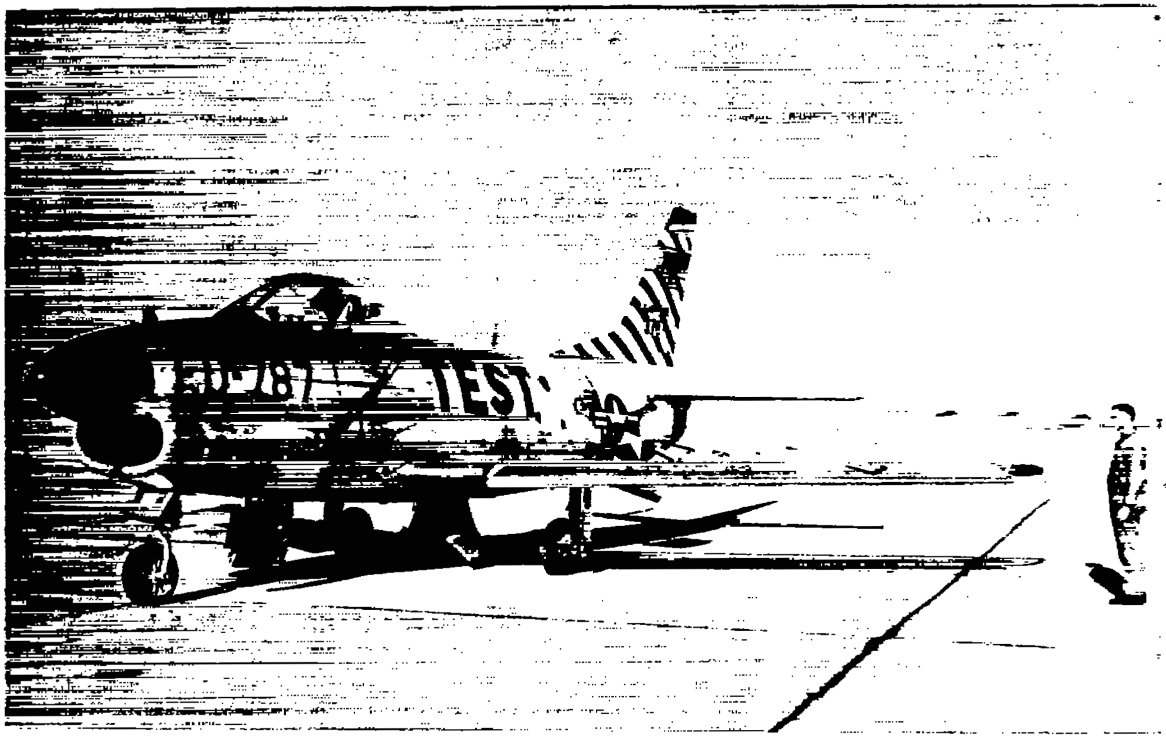

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Figure 1.- Photograph of test airplane.

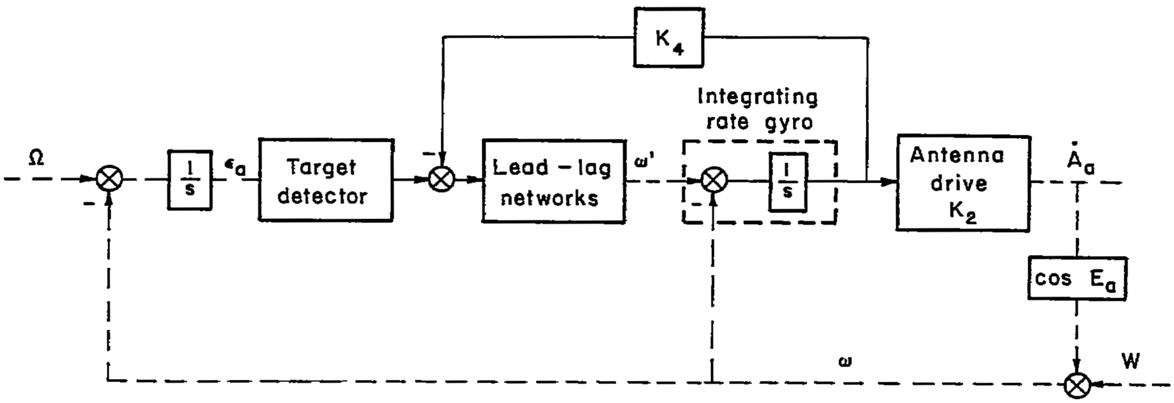
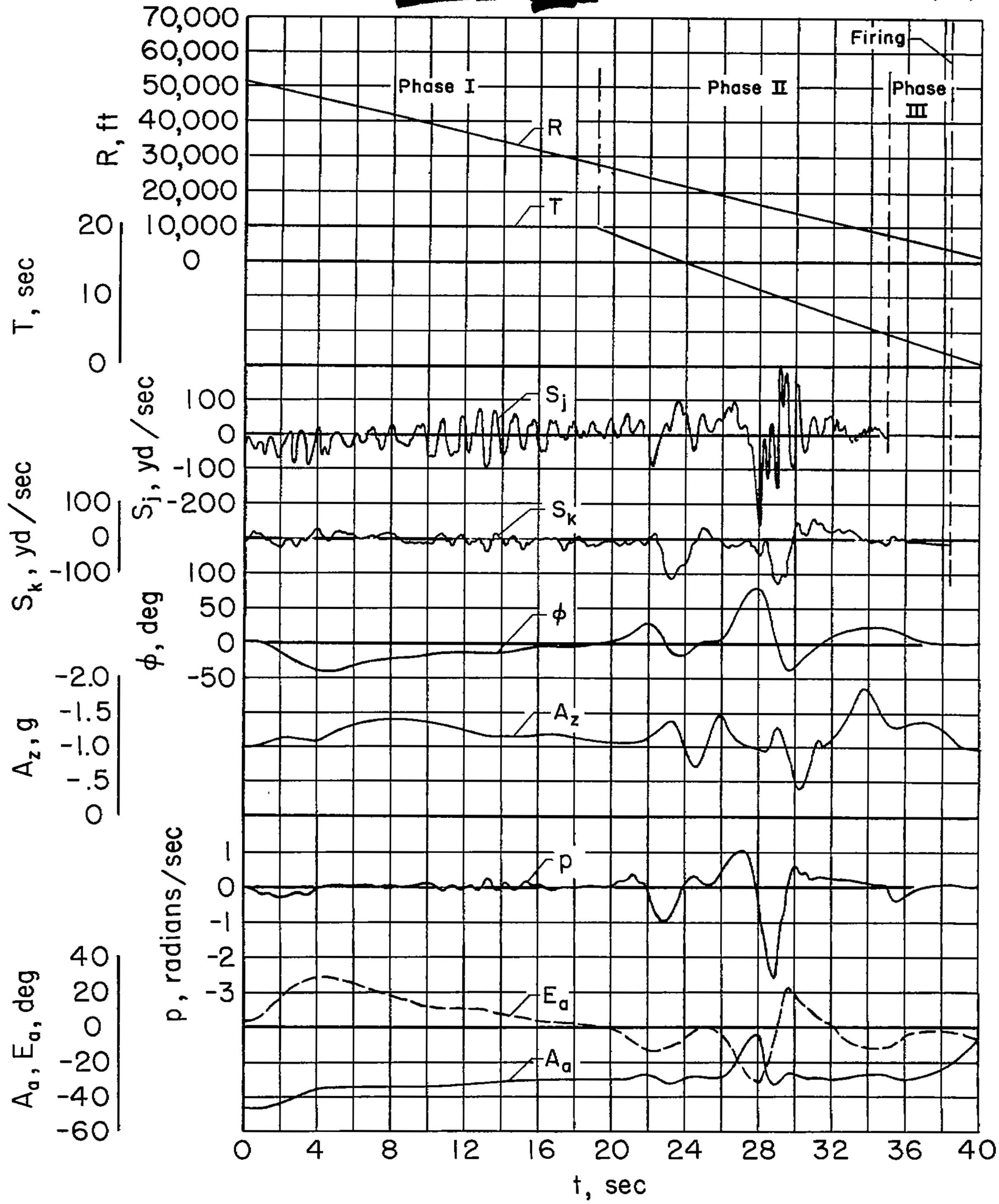


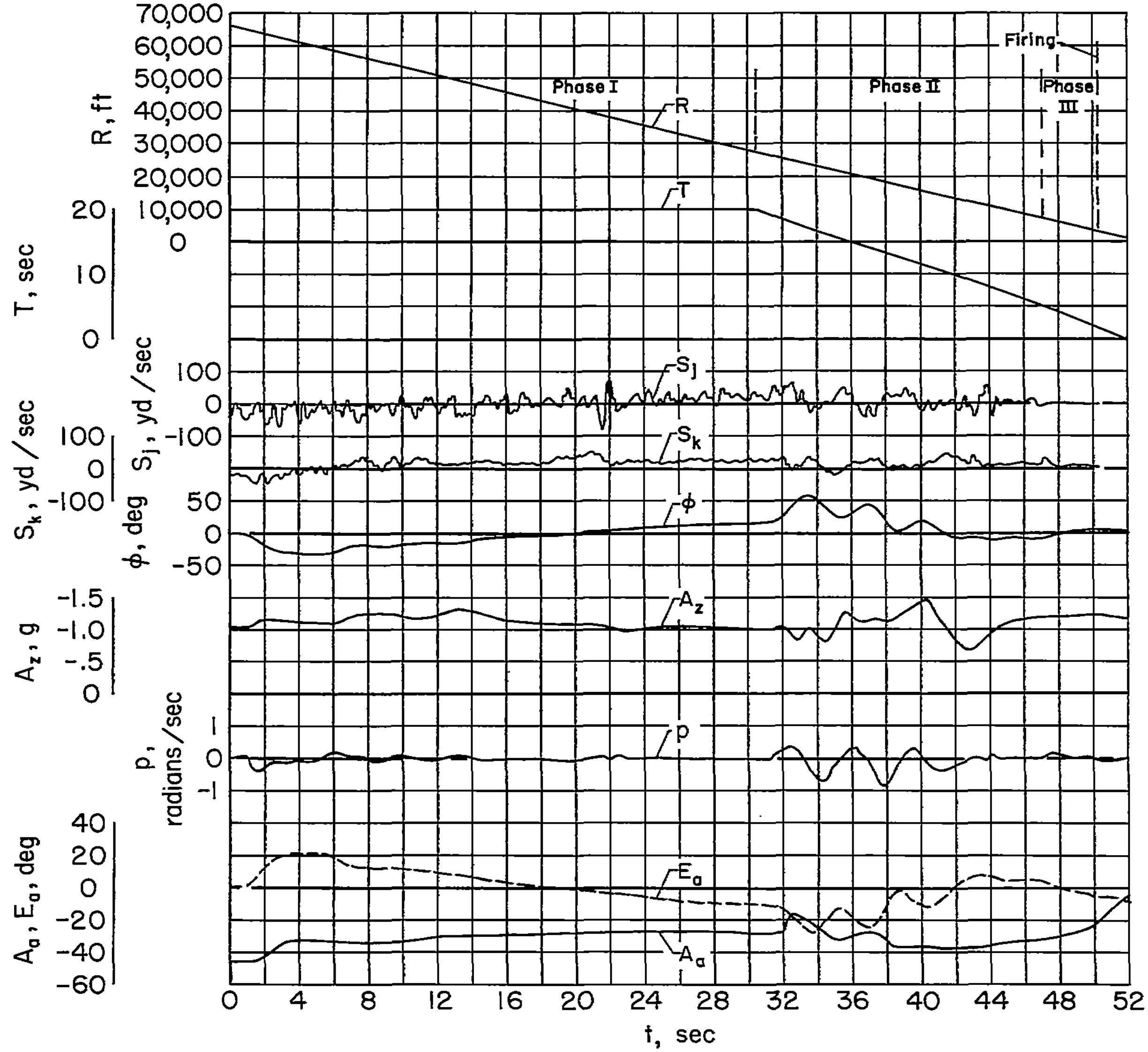
Figure 2.- Simplified block diagram of azimuth channel of radar including compensating feedback.



(a) Normal system; $K_2 \approx 35$, $K_4 = 0$.

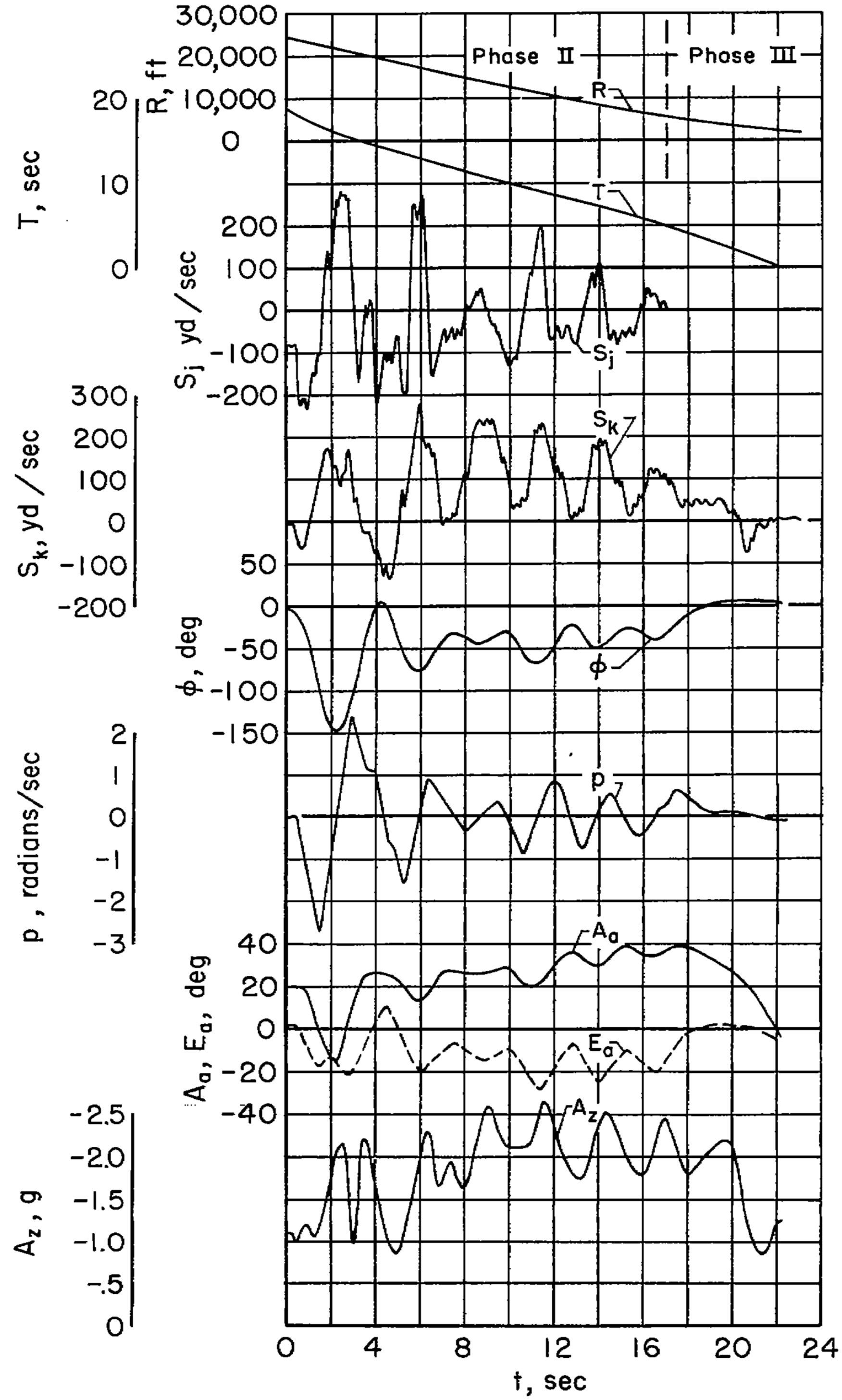
Figure 3.- Time history of beam attack.

[redacted]



(b) Modified system; $K_2 \approx 35$, $K_4 \approx 0.7$.

Figure 3.- Concluded.



(a) Normal system; $K_2 \approx 28$, $K_4 = 0$.

Figure 4.- Time history of beam attack; short lock-on range, negative azimuth steering error.

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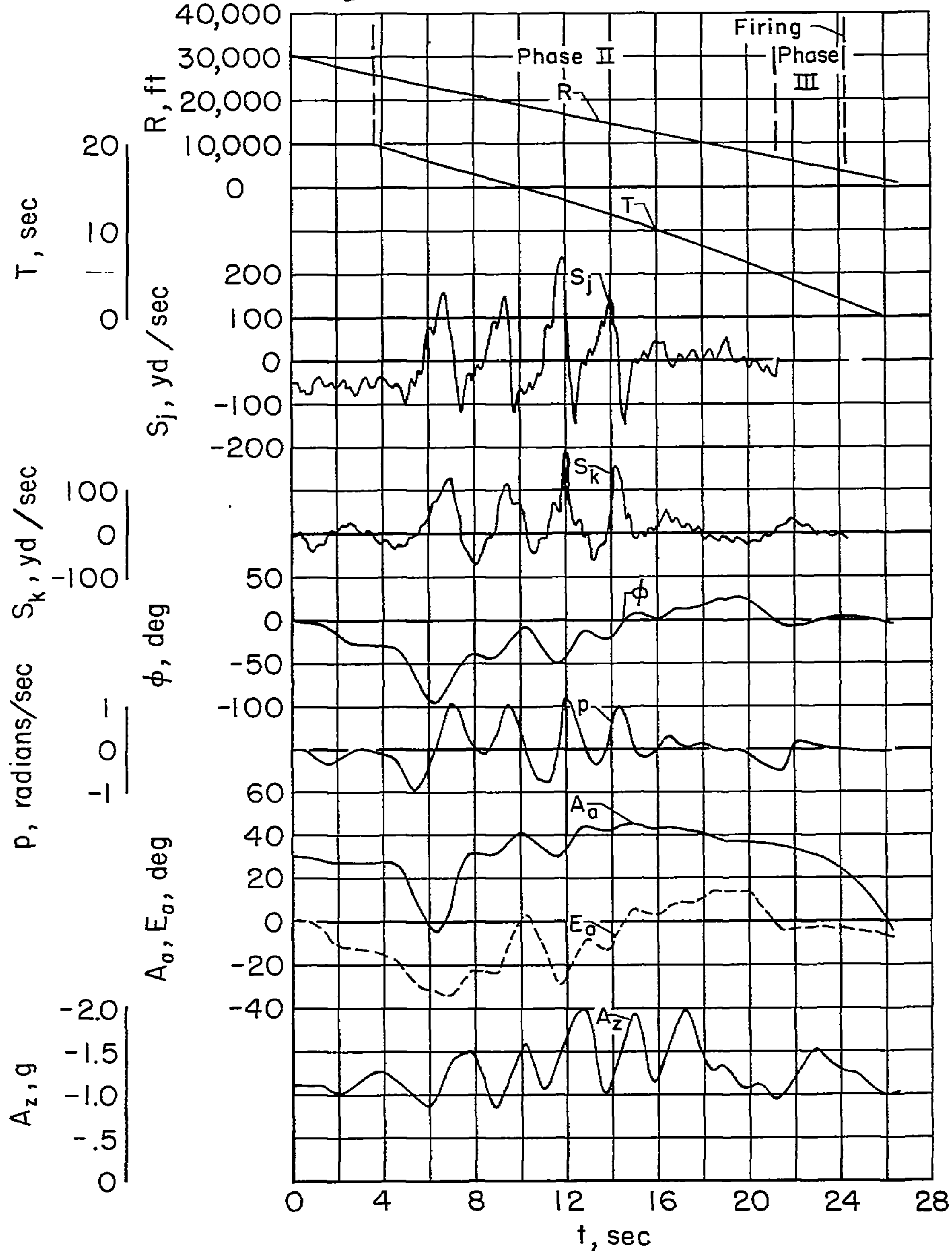

(b) Modified system; $K_2 \approx 28$, $K_4 \approx 0.7$.

Figure 4.- Concluded.

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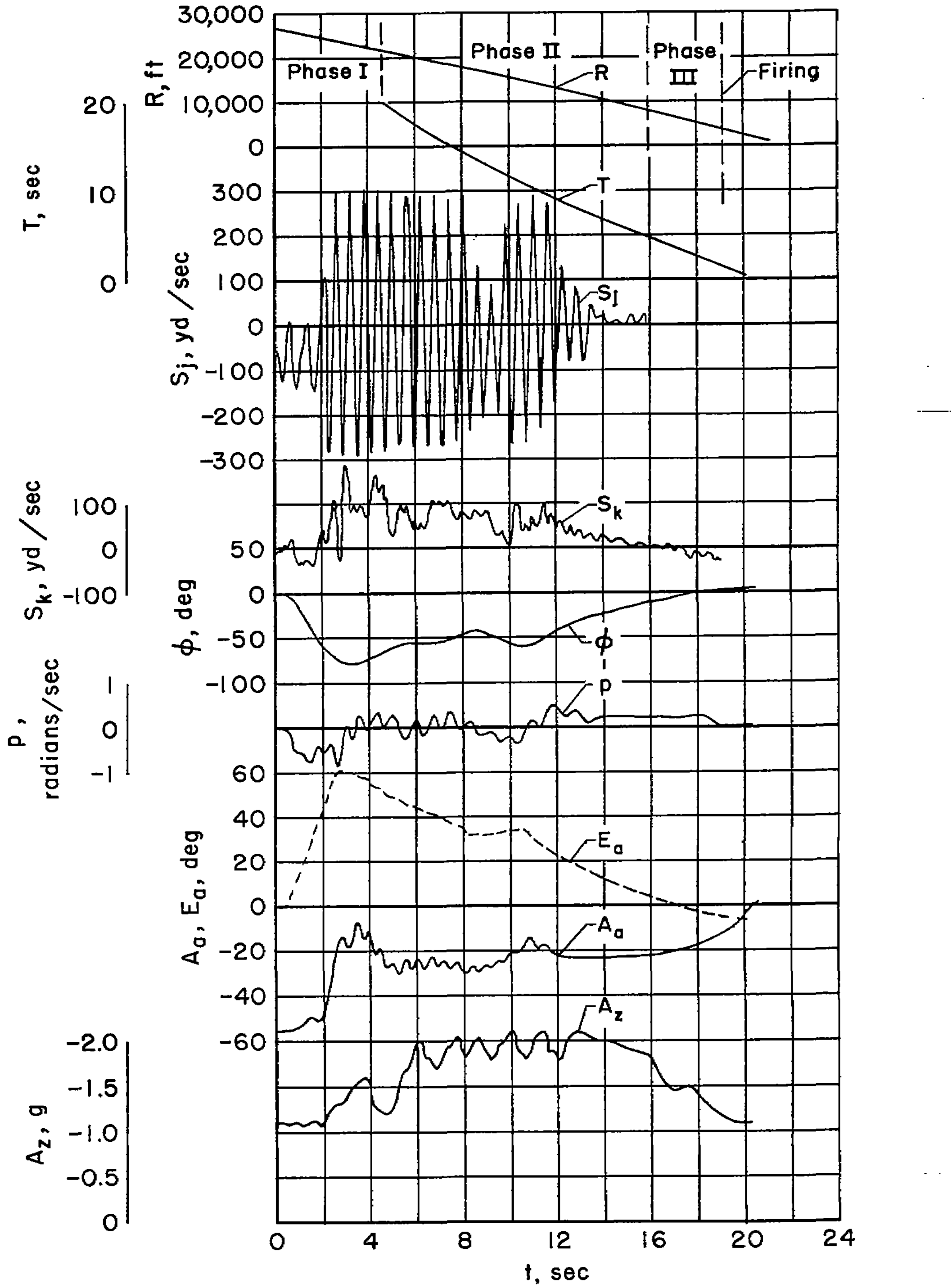
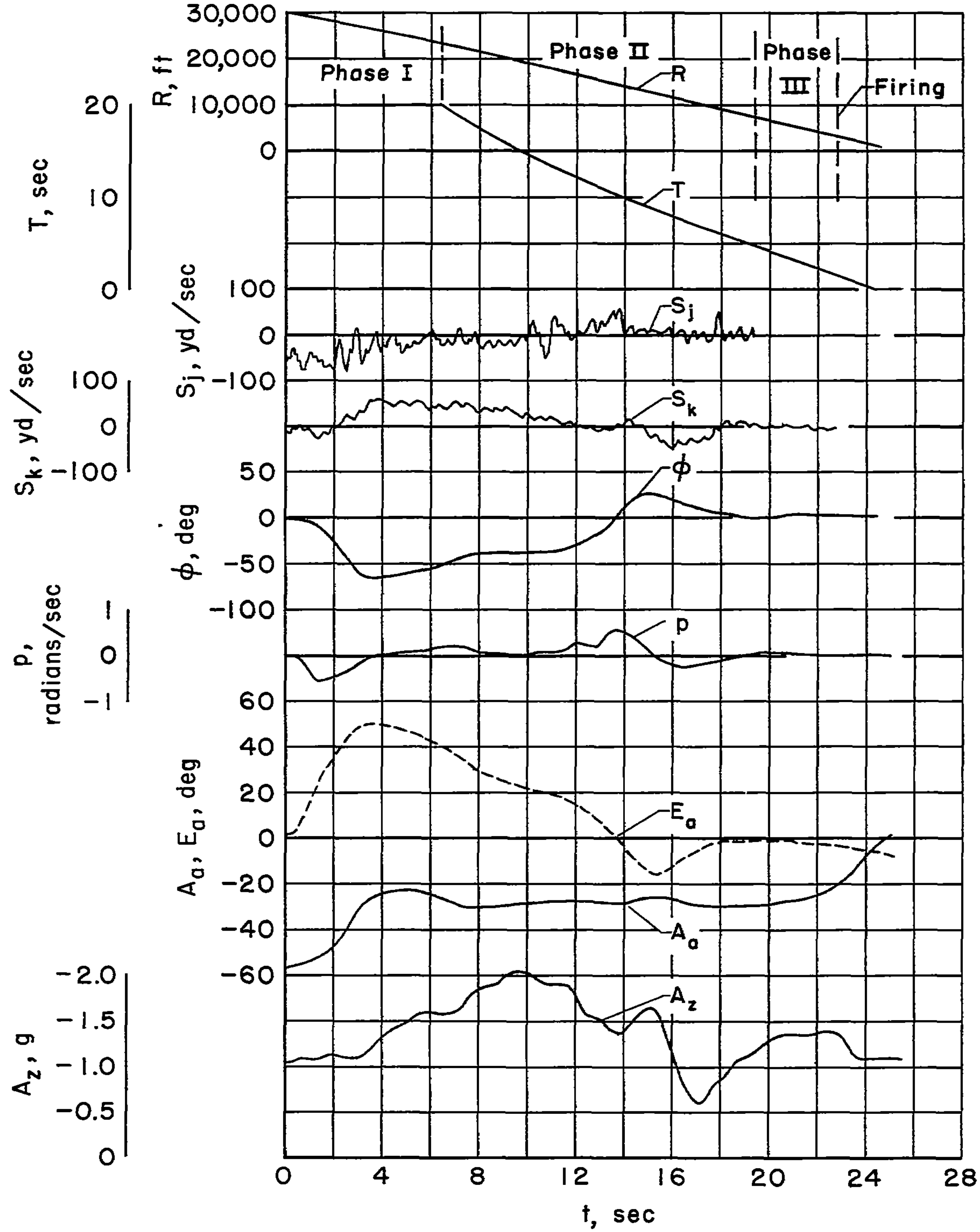


(a) Normal system; $K_2 \approx 28$, $K_4 = 0$.

Figure 5.- Time history of beam attack; short lock-on range, positive azimuth steering error.



(b) Modified system; $K_2 \approx 28$, $K_4 \approx 0.7$.

Figure 5.- Concluded.

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